Cosmology: The State of the Universe

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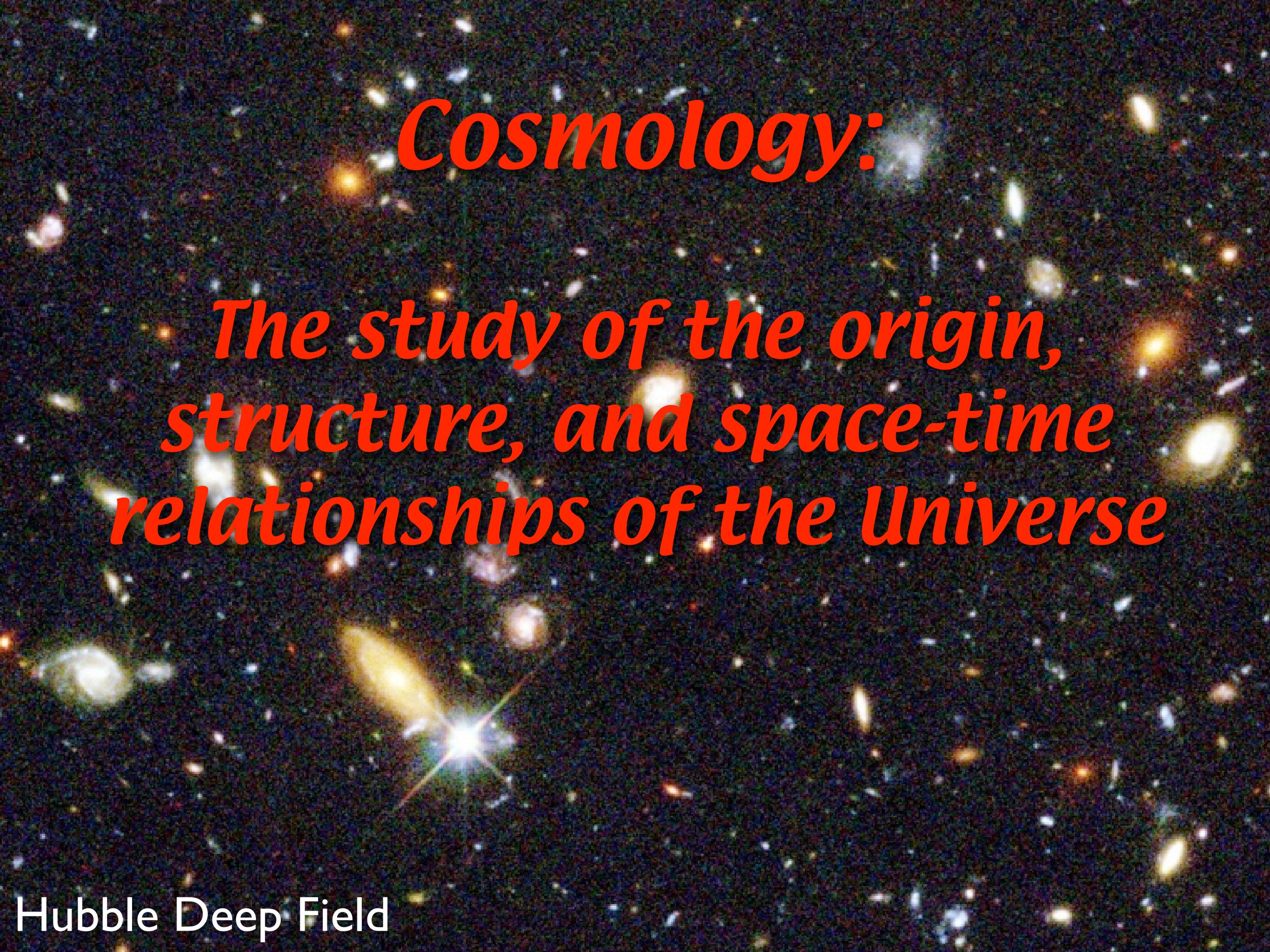
Los Alamos, July 2008

CGCG180-023: A ring galaxy observed by the Sloan Digital Sky Survey

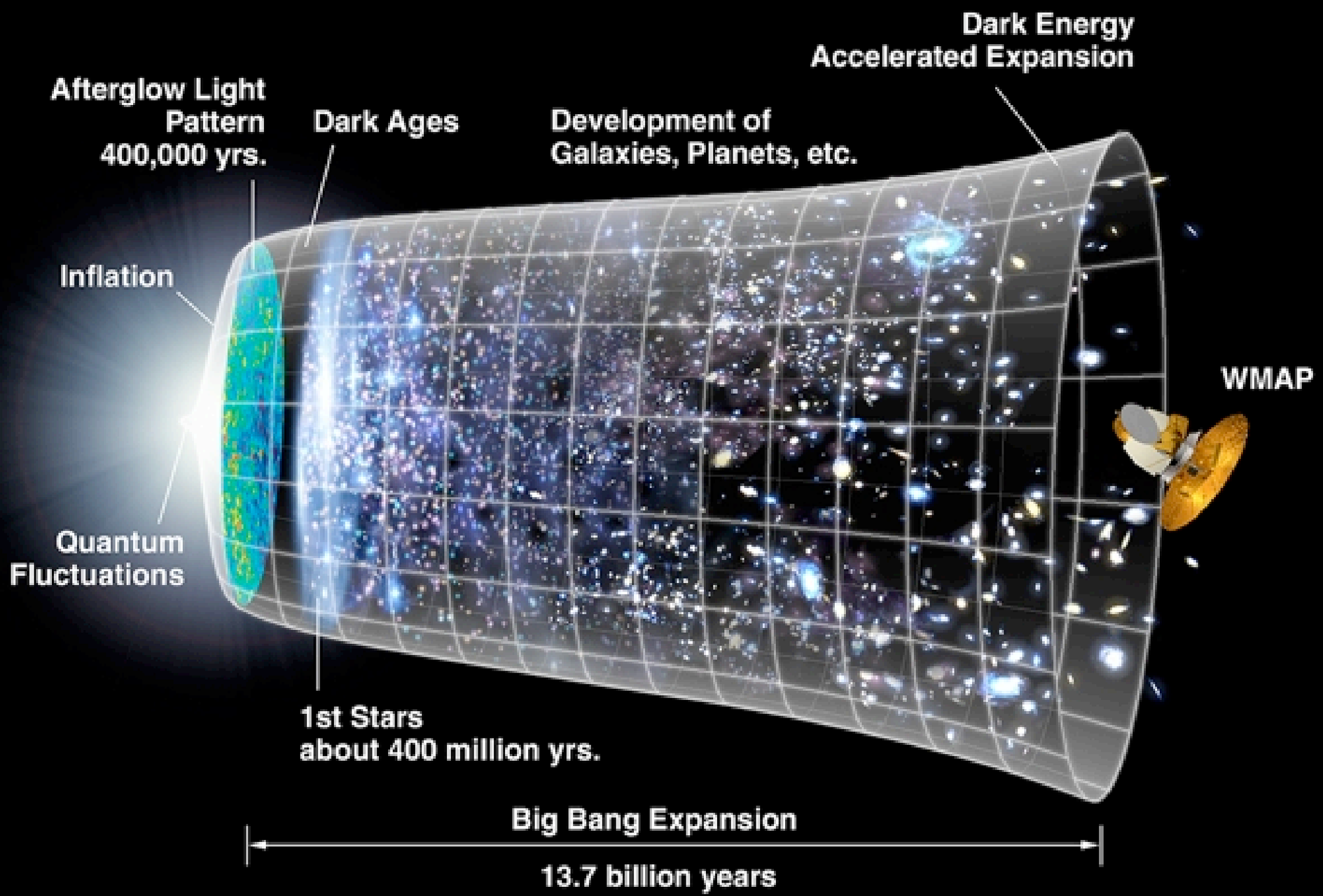
Further reading and references: http://map.gsfc.nasa.gov/universe

Cosmology:

The study of the origin, structure, and space-time relationships of the Universe

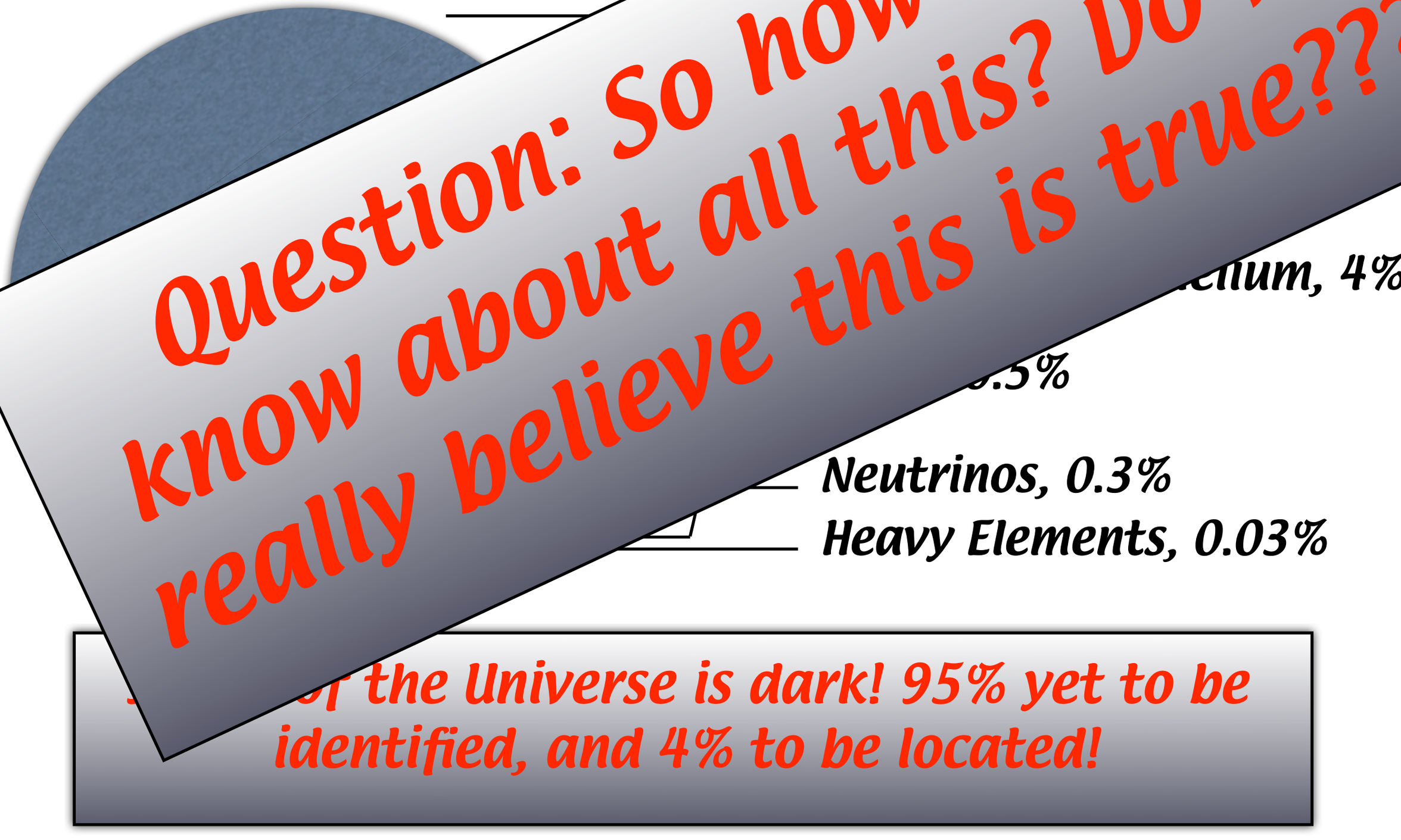


Hubble Deep Field



http://map.gsfc.nasa.gov/

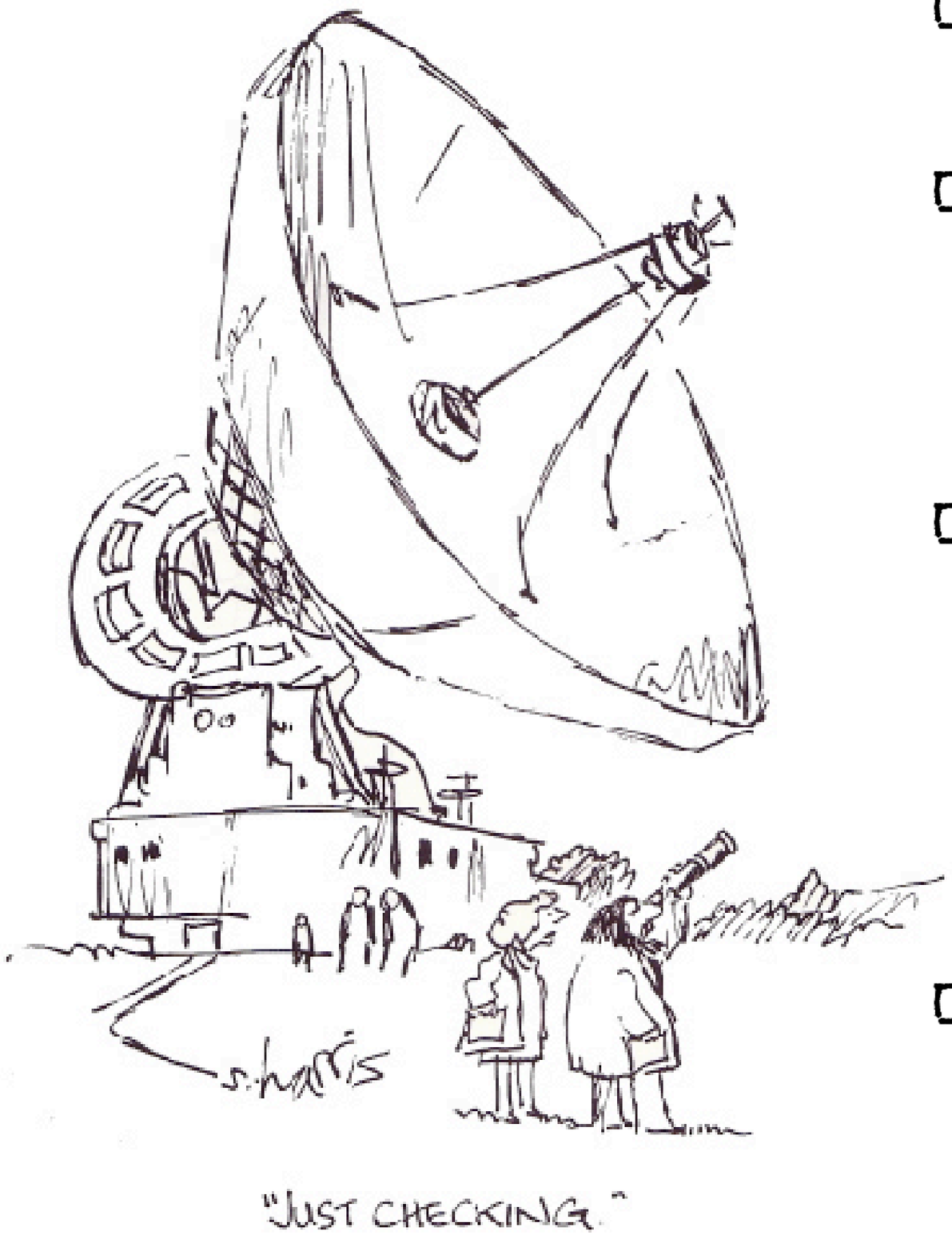
What we (think) we k… U



Question: So how do we know about all this? Do we really believe this is true???

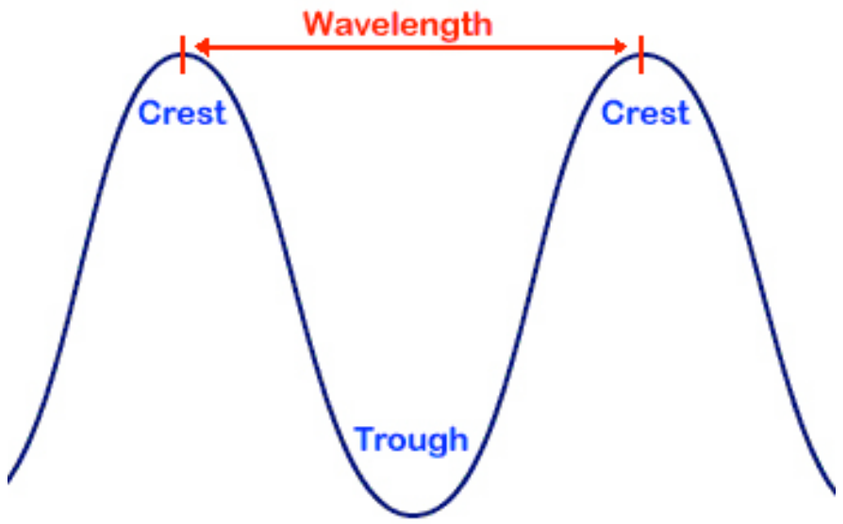
…of the Universe is dark! 95% yet to be identified, and 4% to be located!

Observations

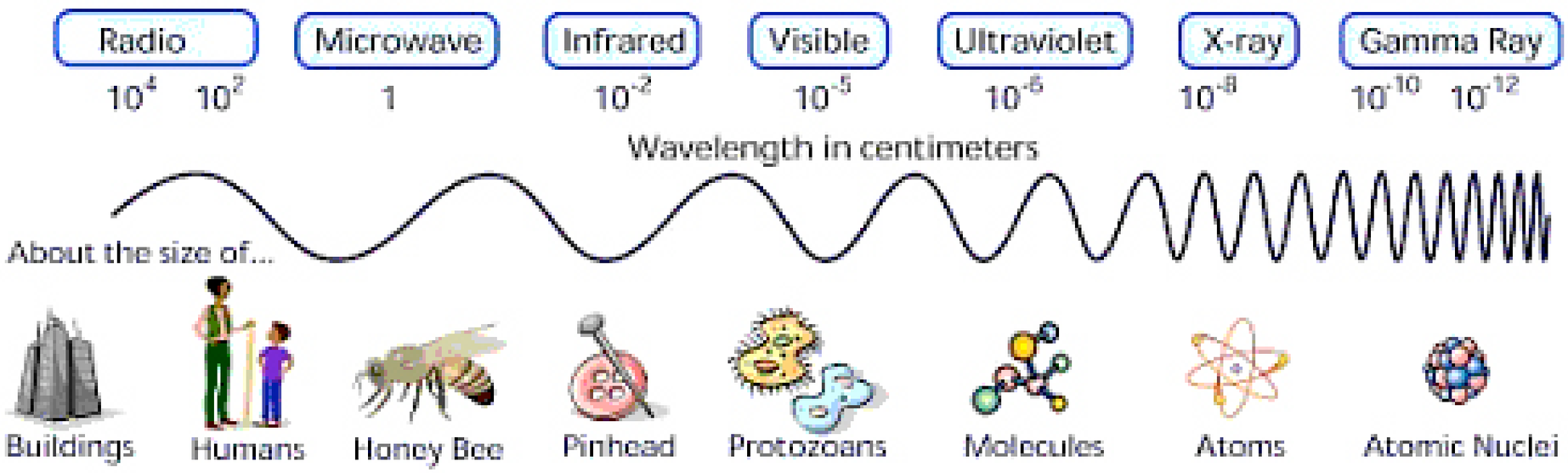


- *In physics:* **Experiments, repeatable, controlled!**
- *In cosmology/astrophysics:* **Observations, unfortunately only one Universe that we can study!**
- *Challenge:* **We have to find different ways to measure cosmological parameters and observe the Universe and its dynamics to have independent cross-checks for our results!**
- *Possibility:* **Observe the Universe at different wavelengths (in day-to-day life: x-ray of broken leg...)**

Photons at Different Wavelengths

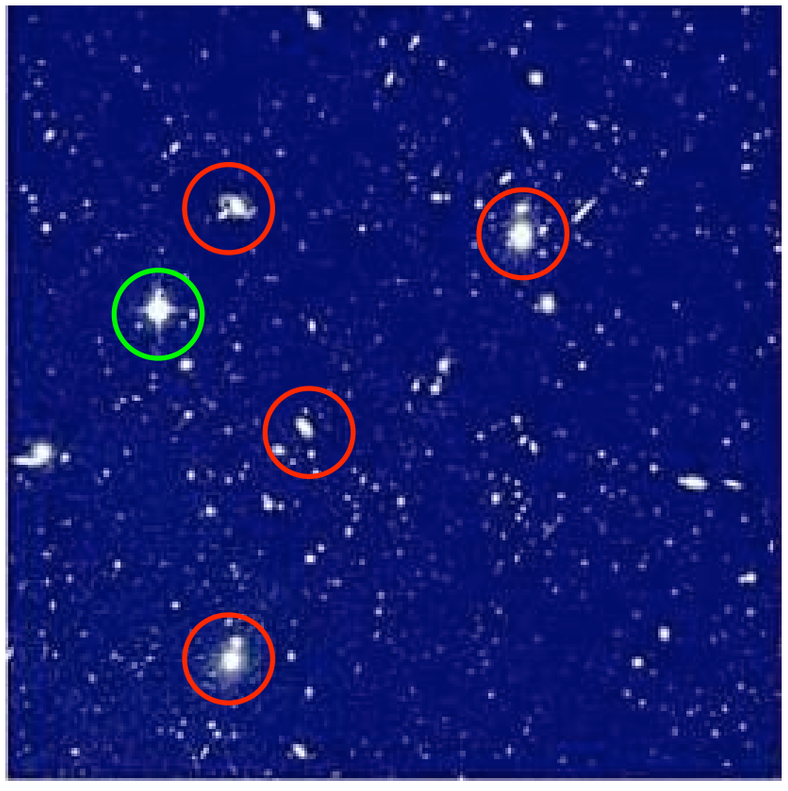


The Electromagnetic Spectrum



An Example: A1367

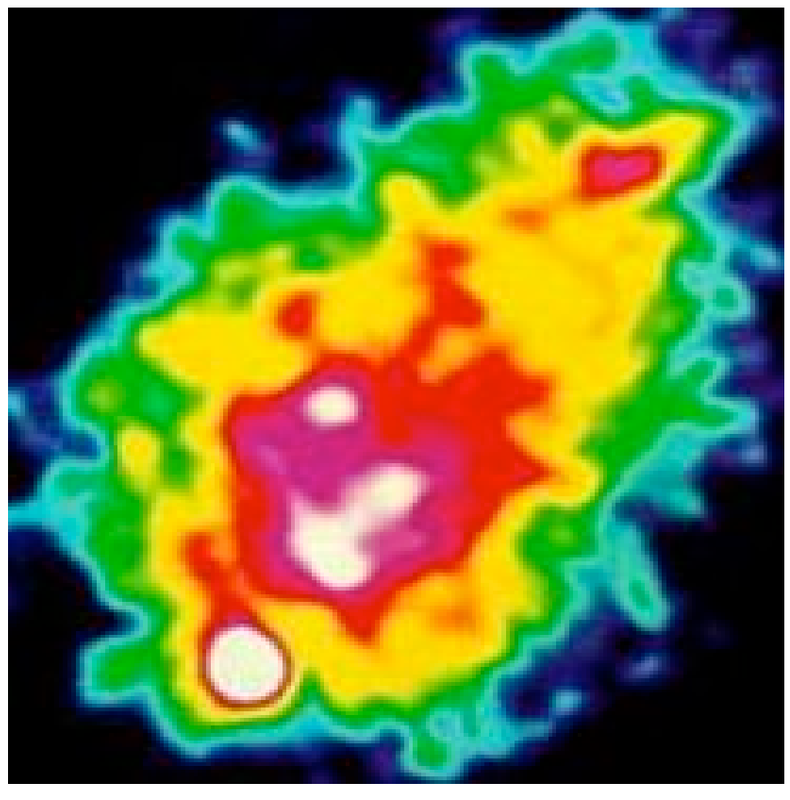
A Cluster of Galaxies at Different Wavelengths

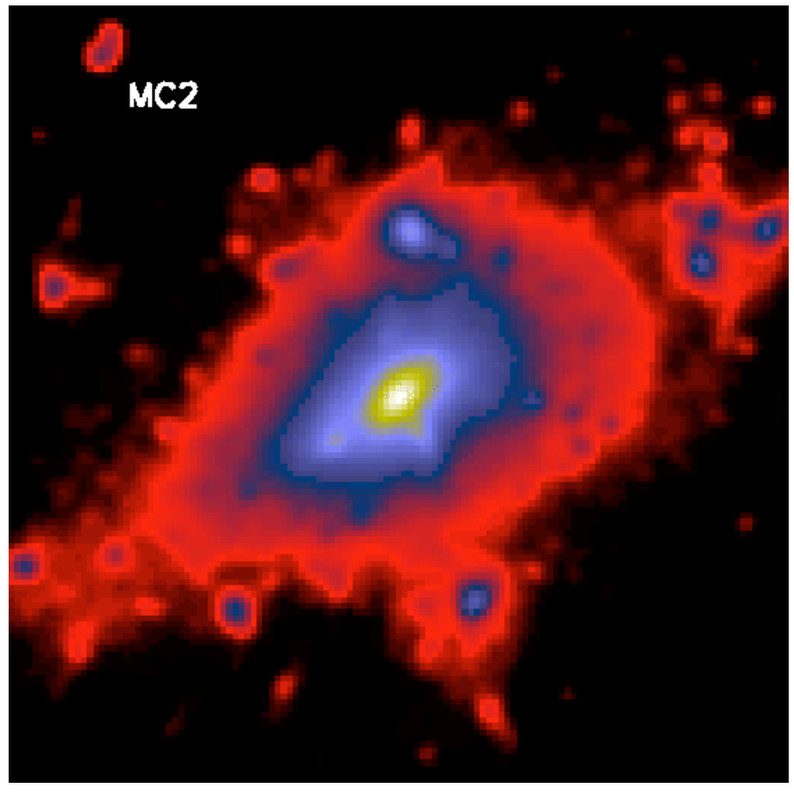


Galaxies Stars

Cluster of galaxies in the optical, galaxies themselves are nicely visible

The same cluster, but in the x-ray, this time we see the gas in the cluster





A simulated cluster, this time we see the dark matter in the cluster

The Universe at Different Wavelengths

http://map.gsfc.nasa.gov/media

Looking Back into the Past...

3.26 light years ~ 3.1*10^13 km ~ 1 parsec (pc)

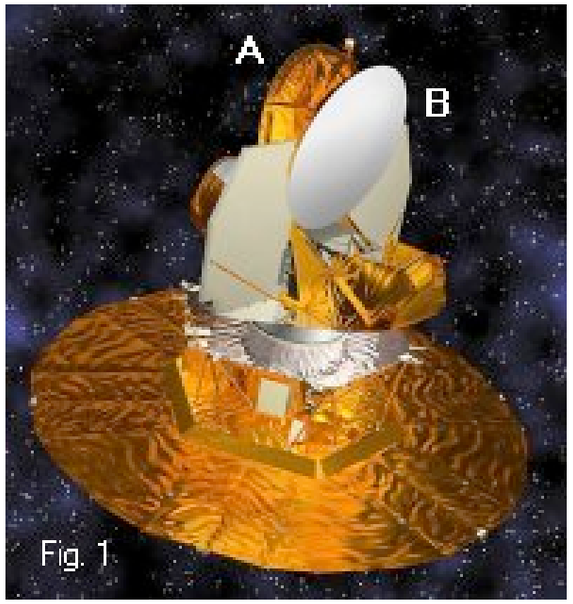
separation of stars in a galaxy ~ 1 pc

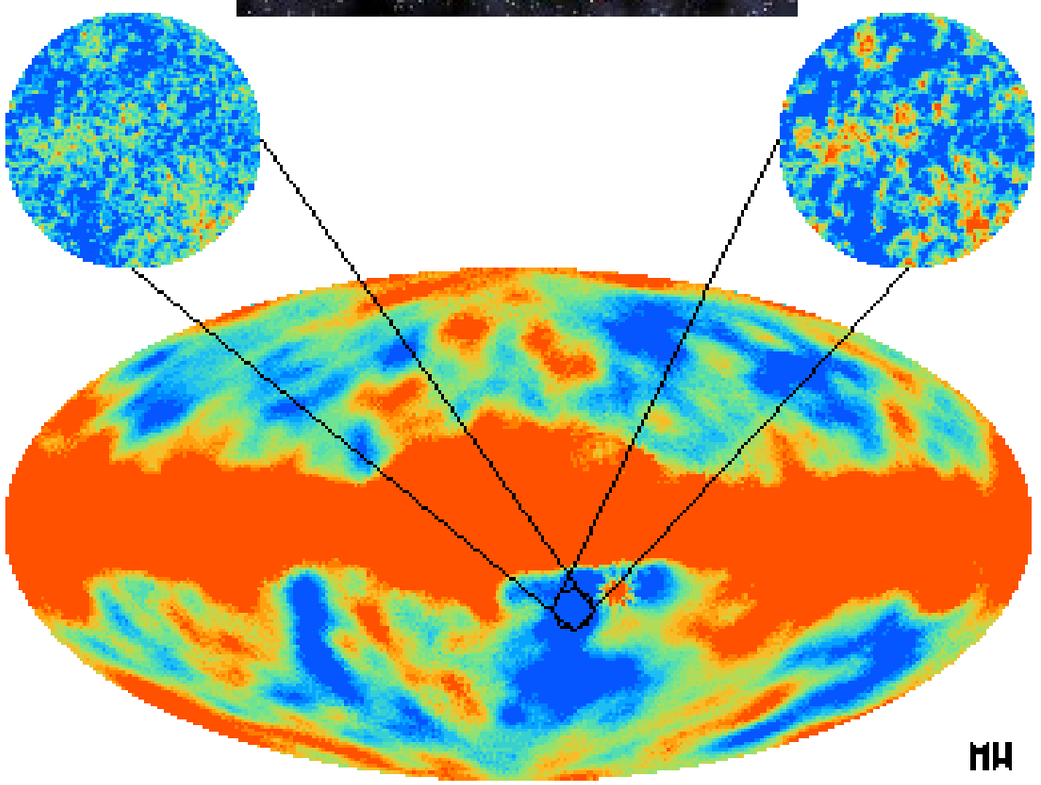
separation of bright galaxies ~ 1,000,000 pc = 1 Mpc

size of the observable Universe ~ 4,500 Mpc = 4.5 Gpc

million years ago!

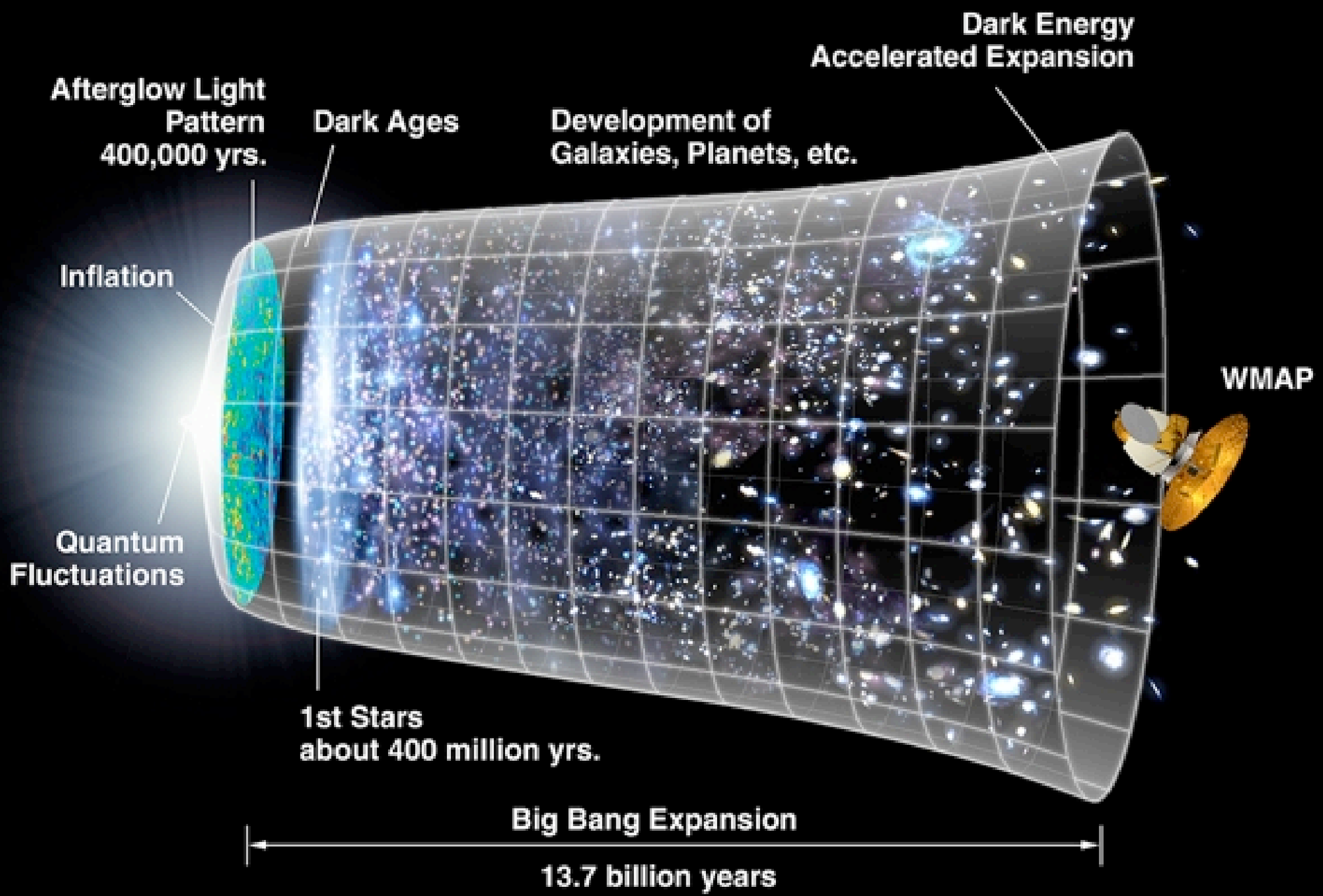
The History of the Universe





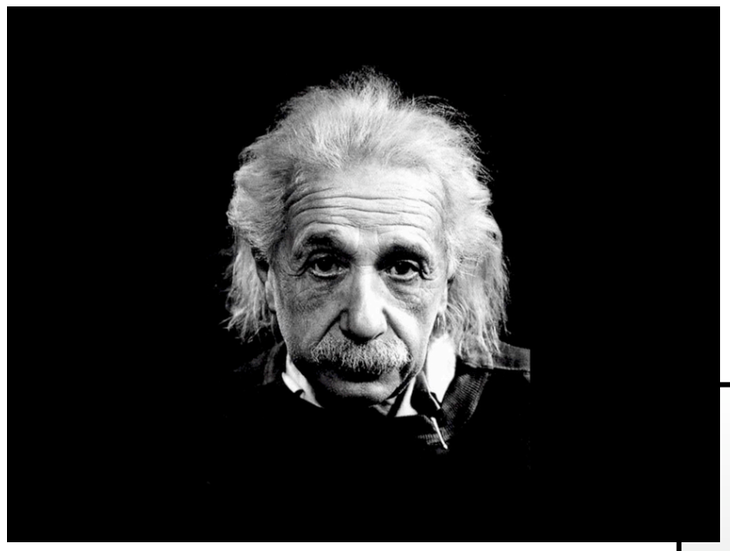
http://map.gsfc.nasa.gov

- After the Big Bang (which was NOT an explosion!) the Universe expanded and cooled down (more on expansion soon!); at this point, the Universe is filled with a hot plasma of photons, baryons, and electrons
- Photons were constantly interacting with the hot plasma
- When the Universe was cooled down to ~30,000K, at the age of 400,000 years, the protons and elecetrons combined to form hydrogen atoms, on which photons scattered off; the photons now could travel freely through the Universe and the Universe became transparent
- Photons continued cooling ever since, now down to 2.725K and we can measure this! => the cosmic microwave background
- Small perturbations were imprinted
- Due to gravitational amplification these tiny perturbations grew and formed the structures (galaxies, clusters,...) which we observe today



Evidence for Dark Energy

The Universe is expanding!



- 1915: Einstein develops general relativity
- Prediction: all of space is dynamic! Either contracting or expanding!
- Einstein puzzled! Introduces "Cosmological Constant" to ensure static Universe

Hubble Diagram, 1929

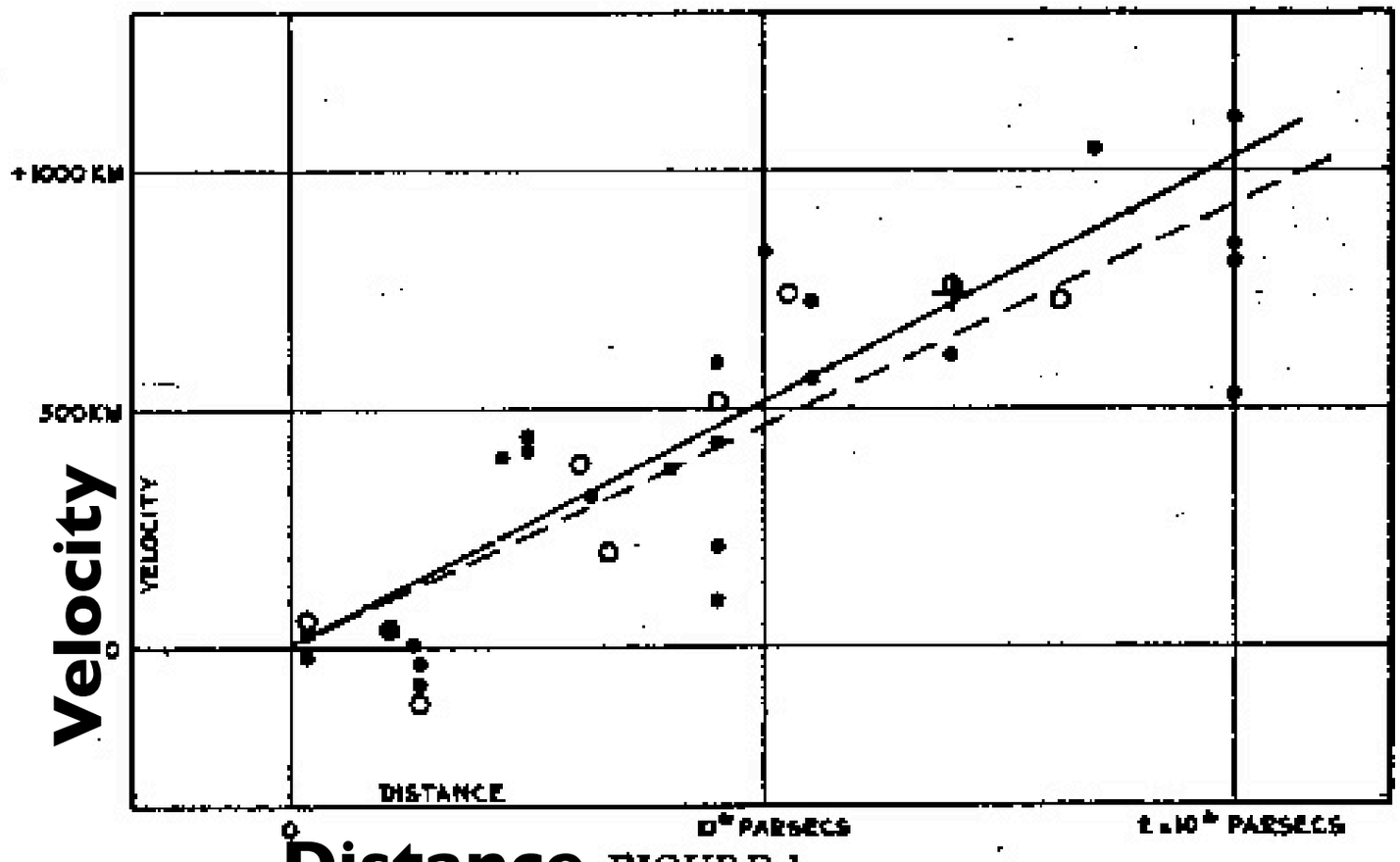


FIGURE 1

* Slipher (Lowell) finds: nebulae are moving away from earth!
* 1923: Hubble starts measurements
* 1929: publication, the Universe is expanding!

http://www.astro.ucla.edu/~wright/DL_vs_z_12May98.gif

The Universe is expanding faster than we thought!

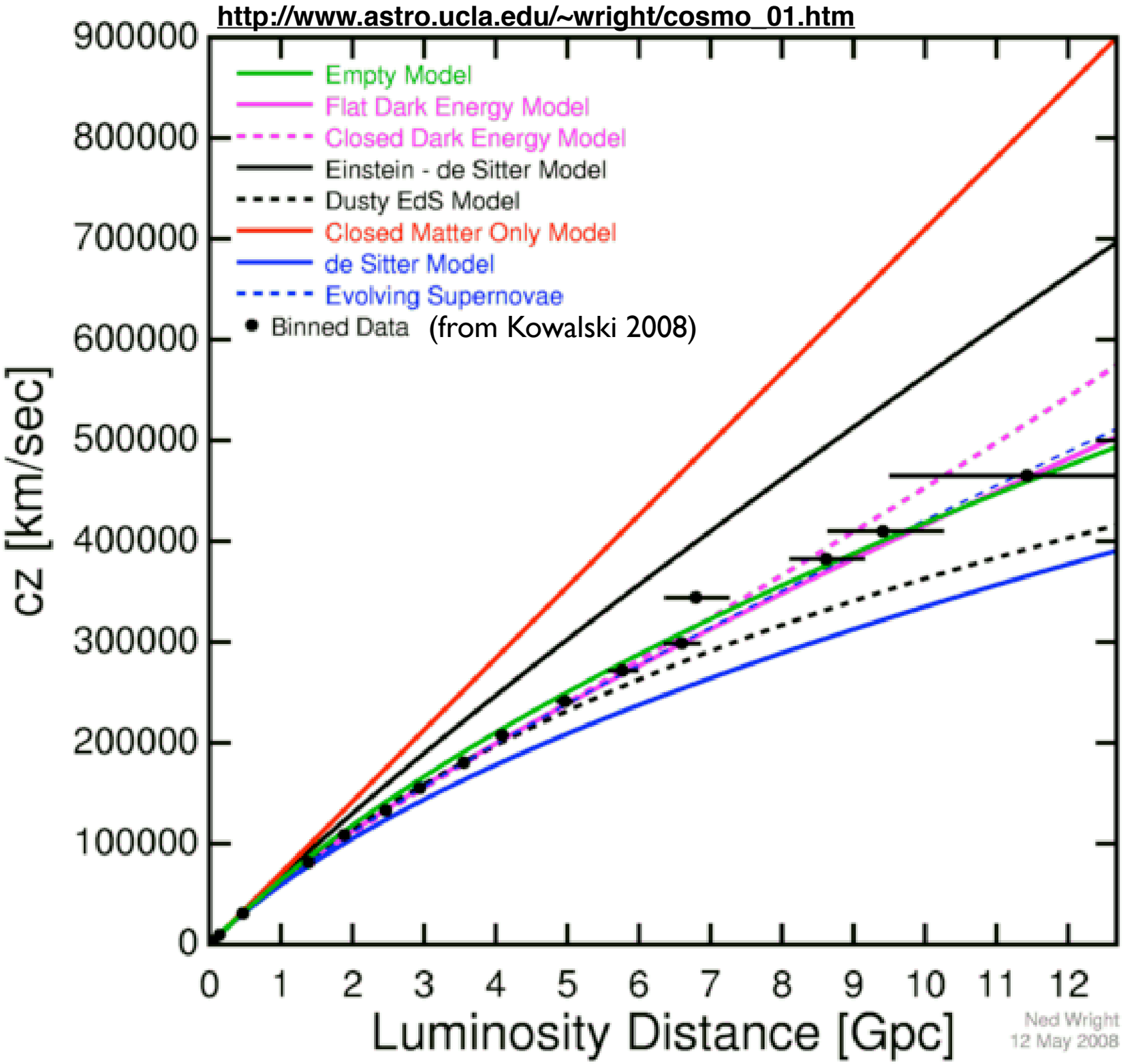
* Supernovae: One of the most energetic explosive events in the Universe, end of the life of a star

* Redshift z: Distance and time indicator (remember constant speed of light!), observed wavelength of a moving object changes! (towards red)

* Expansion rate = 1/(1+redshift)

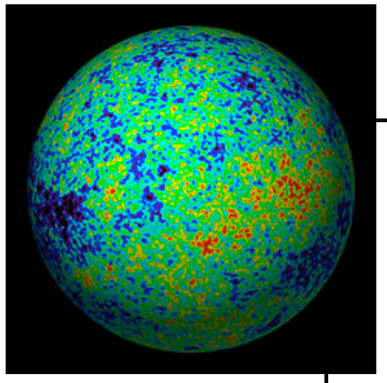
z=1: Universe was half of its current size

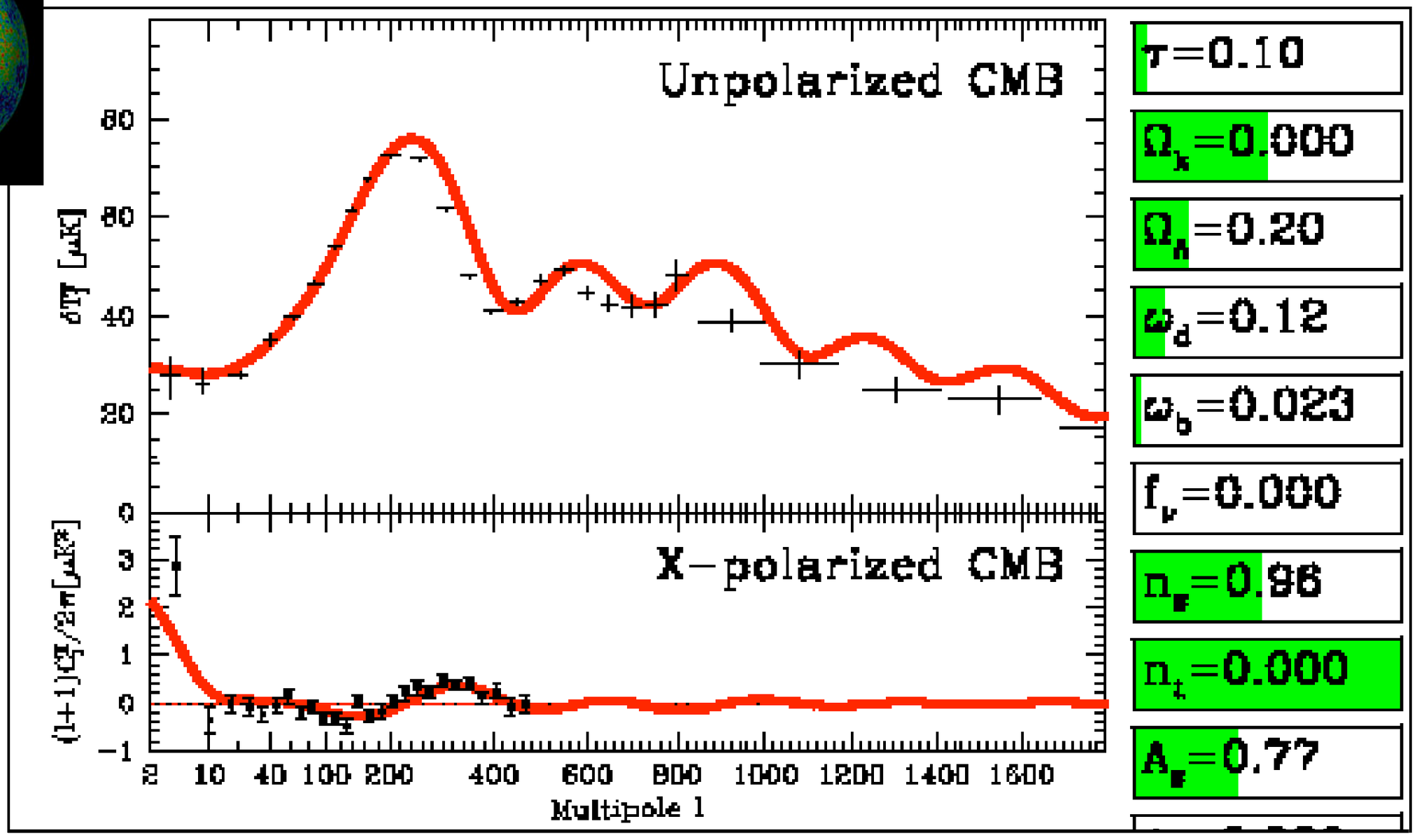
Measurements from the Supernovae



Not yet convinced?

Measurements from the Cosmic Microwave Background





From Max Tegmark: http://space.mit.edu/home/tegmark/index.html
Data from different observations: WMAP, CBI, ACBAR

Still not convinced? There are even more tests...

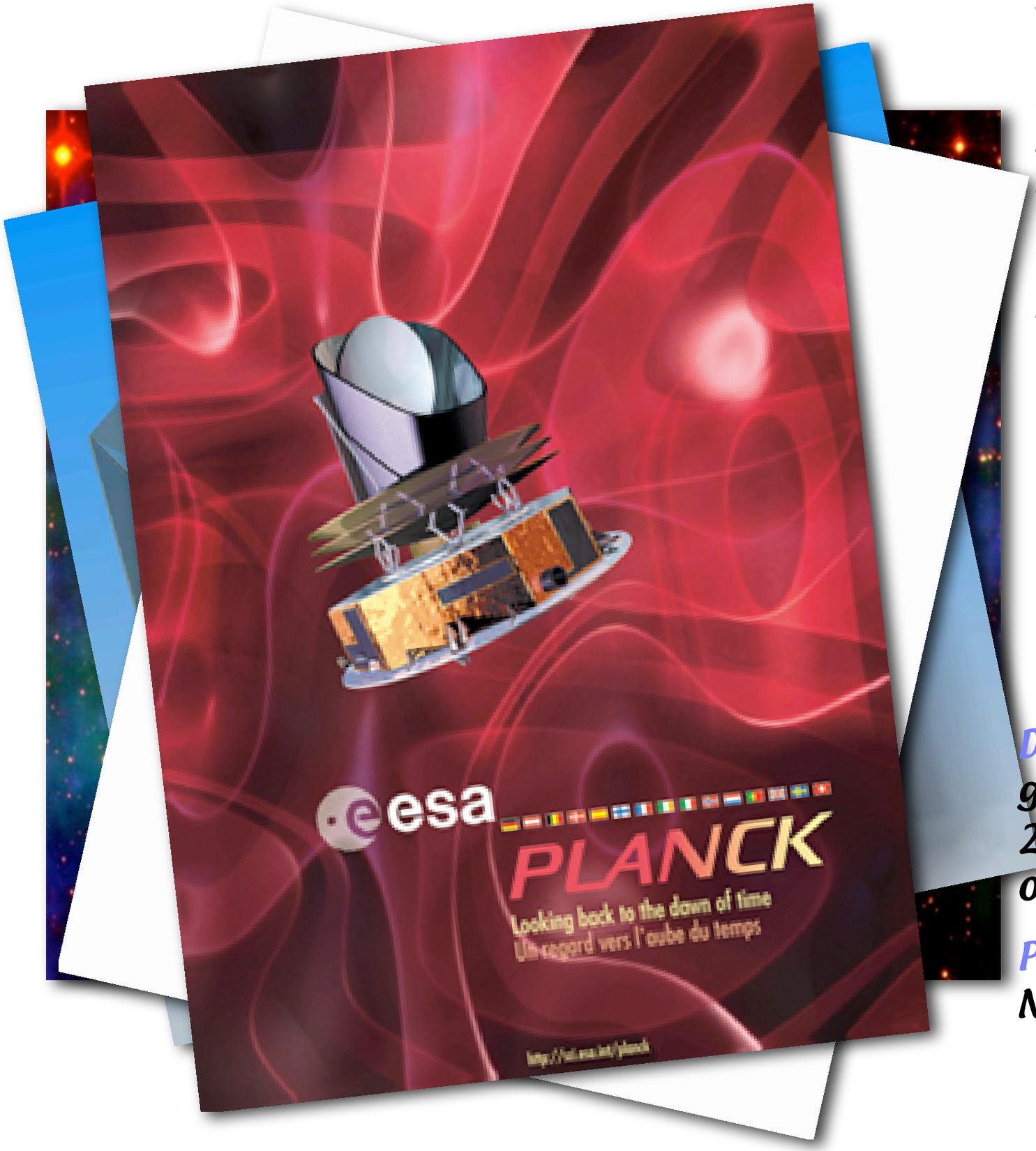
So, what IS dark energy?

Short answer: we don't know!

Quote: "Unveiling this mystery will most probably reveal new physics and might even shake modern particle-physics to its very foundations"

Lots of new and interesting discoveries have to be made!

Planned and upcoming Observations



SNAP (Supernova Acceleration Probe):
2000 supernovae on 15 square degree, 300-1000 square degree lensing survey, Ωm, Ω∧, Ωtot: 1% accuracy, ω: 4%, dω/dt: 10%

SPT (South Pole Telescope):
10 meter diameter telescope, many thousands of clusters, strong constraints on ω

LSST (Large Synoptic Survey Telescope):
8.4 meter, digital imaging across entire sky, supernovae etc., constraints on ω

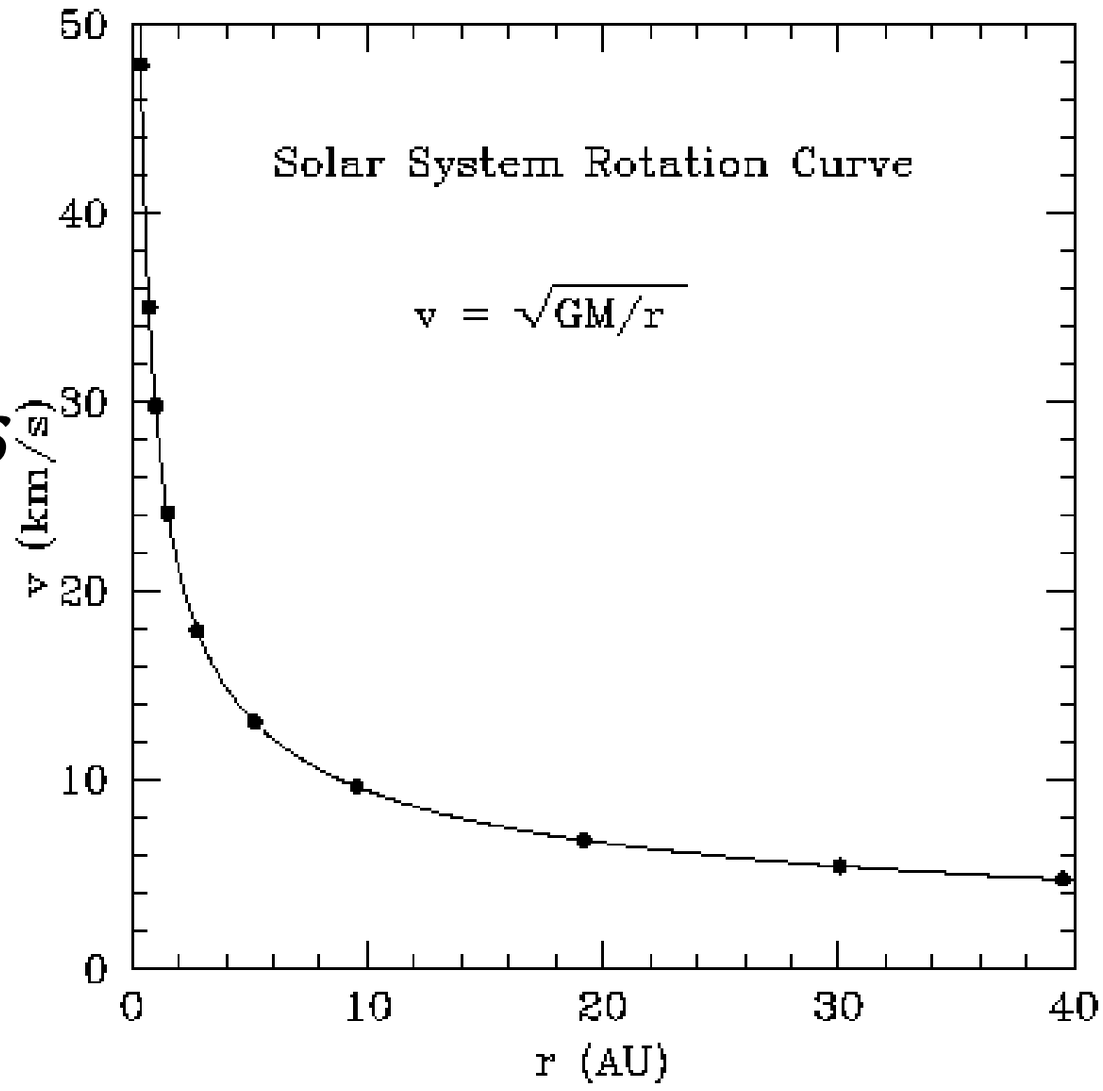
DES (Dark Energy Survey):
galaxy cluster study, weak lensing, 2000 SNe Ia, constraints on ω at the one percent level

PLANCK:
Next-generation CMB mission

Another Mystery: Dark Matter

The First Evidence: Rotation Curves of Galaxies

- Solar system: planets at the outskirts of the solar system need more time to go around the sun than planets closer to the sun
- Example: Pluto takes 249 years to go around the sun, even though its path is only 40 times that of earth
- In agreement with Newton/ Kepler, velocity falls off the farther the planet is away from the center, rotation curve falls off



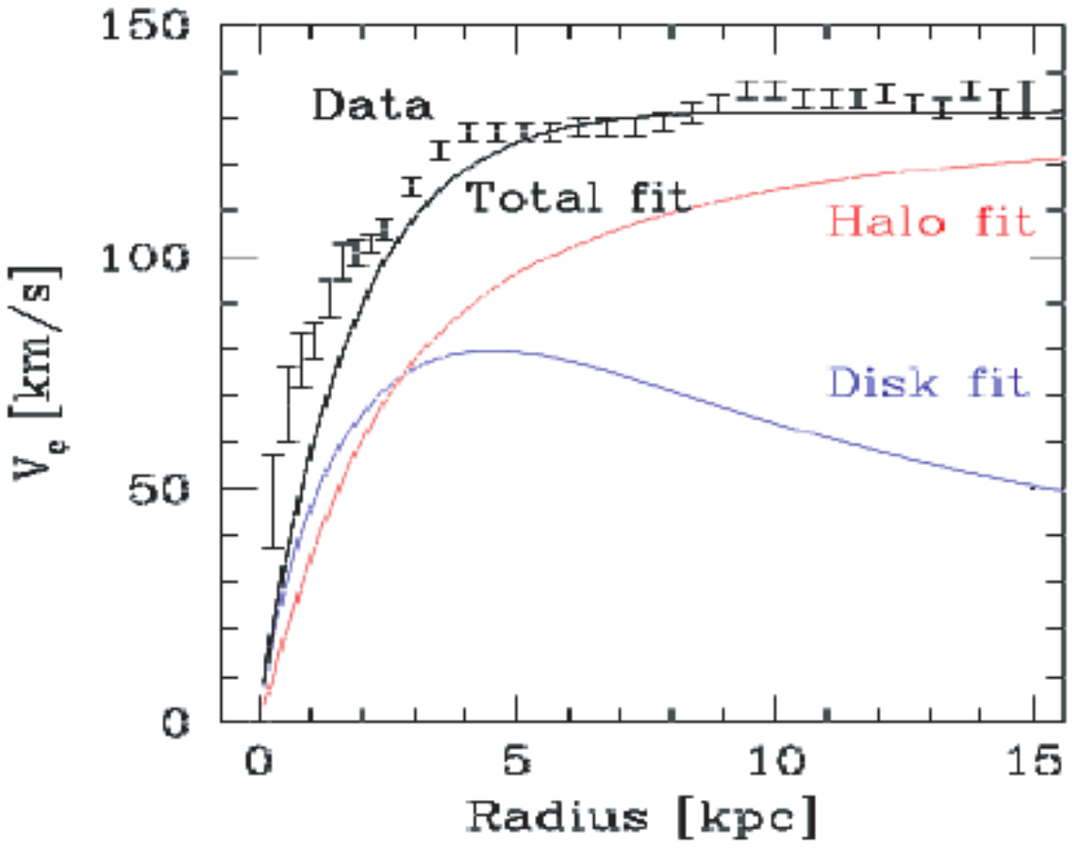
The First Evidence: Rotation Curves of Galaxies

- Same should be true for stars around a galactic center, the further out, the slower

- Observation (1930'): Rotational velocity of stars in Andromeda does not drop off in the outer regions of the galaxy! Instead speed levels of at constant value! True for other galaxies.

What is this ???

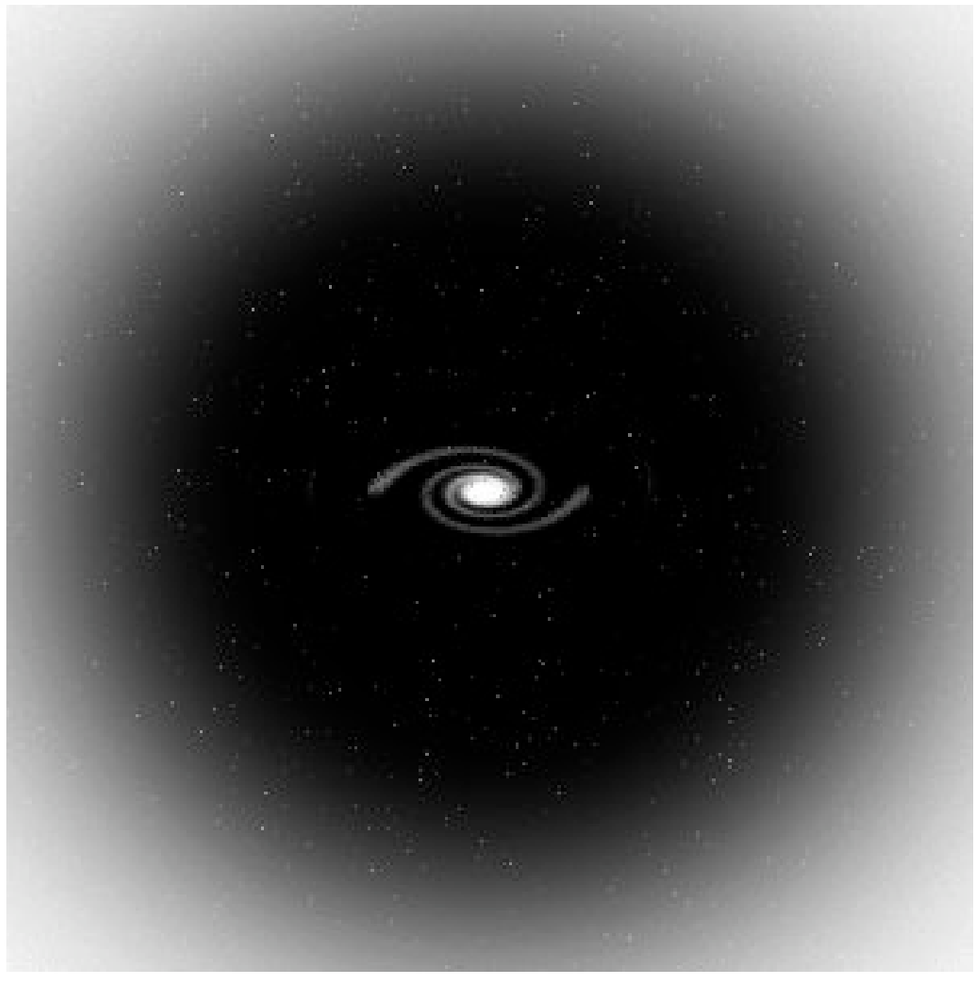
Andromeda (M31), a spiral galaxy



The First Evidence: Rotation Curves of Galaxies

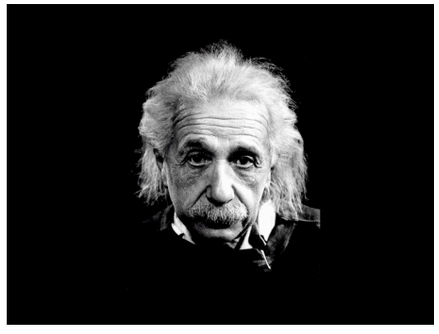
- Newton and Kepler didn't know what they were doing... OH, OH...

- Easier solution: there is more mass than we see! Dark matter!

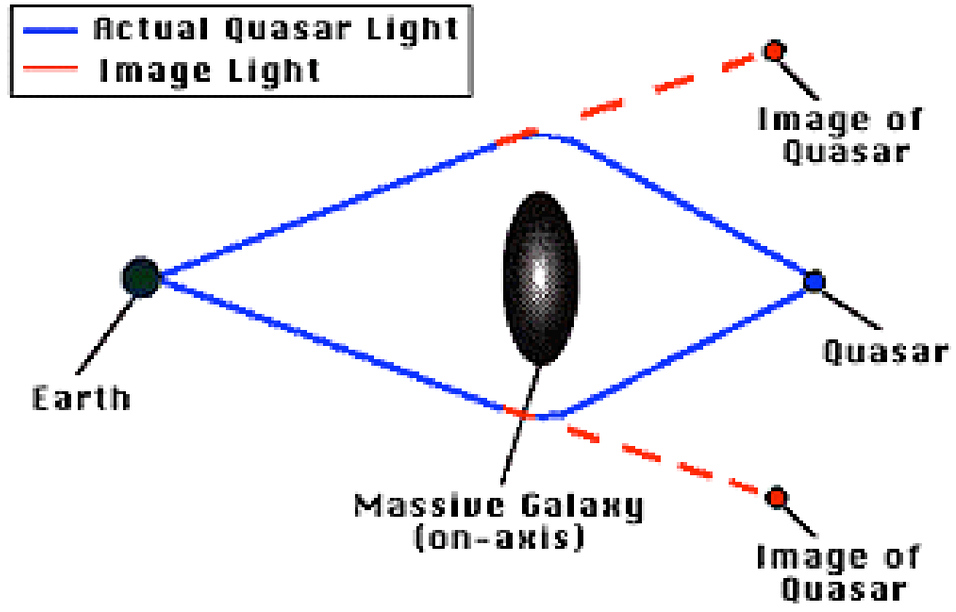


- Moreover: theory predicts that thin rotating discs as these spiral galaxies are simply not stable enough to hold together on their gravitational force, they should fly appart! A halo of dark matter could stabilize them!

The Second Evidence: Lensing



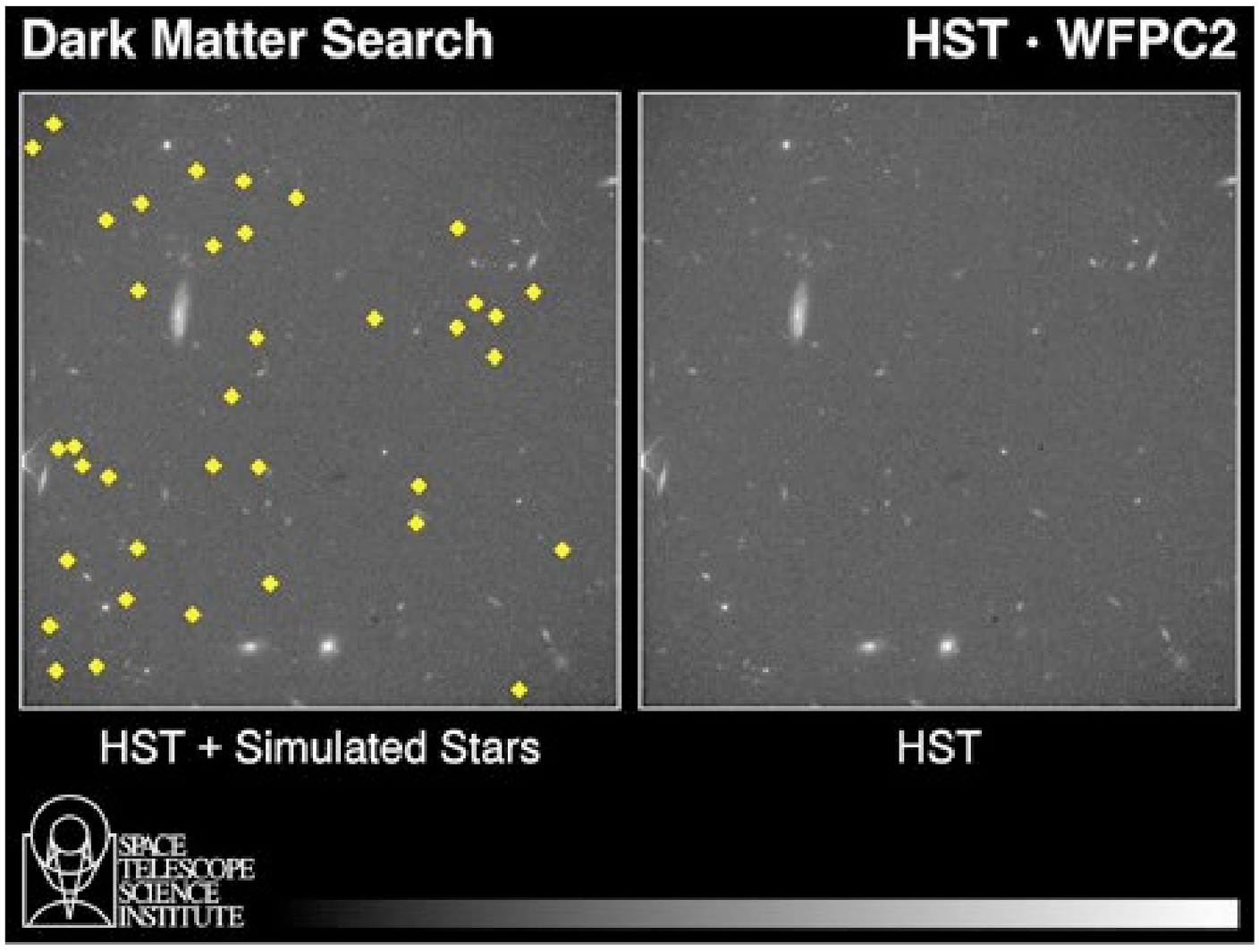
- General relativity: matter can curve space-time, path of light will be deflected as a result



- Strong lensing: lens is very massive and source close, light can take different path to the observer, more than one image will appear!

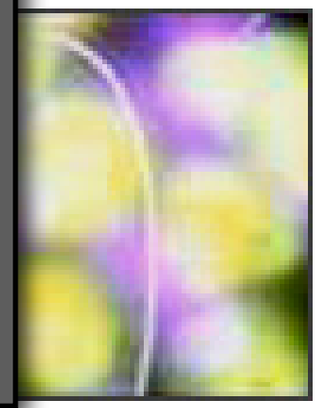
* Dwarfs: normal size stars for their weight, e.g., the sun is a dwarf star
* Come in different colors: brown, black, red...
*Brown dwarfs: failed stars, never heated up enough to explode into a real star

Problem with baryonic dark matter: there is not enough of it!



- *Hubble Space Telescope image of a randomly selected area of the sky*
- *Left: simulation, yellow diamonds respresent how many stars should be there, if they are the main contributor to dark matter*
- *Right: actual observation*

*Neutrino: one of the fundamental particles, sort of similar to the electron, but no charge, almost no mass, comes in three flavors, interacts only weakly and via gravitation



- Poss
  neut
- WIM
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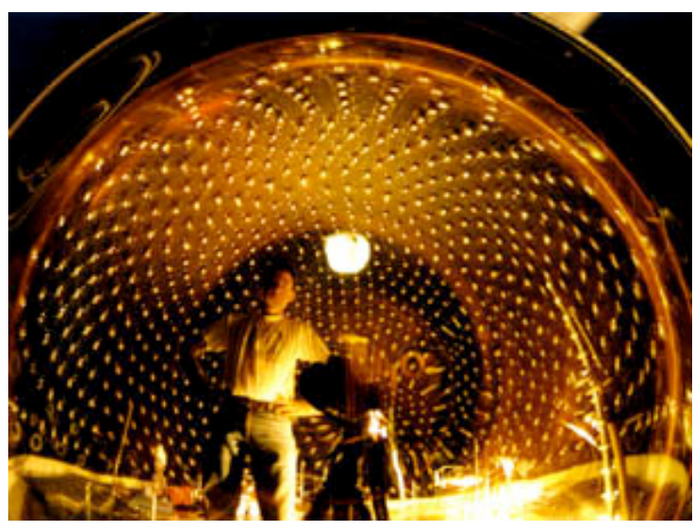
ZILLA: favored by Rocky Kolb (Professor at the University of Chicago), very heavy weakly interacting particle

How can we find them? Ongoing Searches

* WIMPS: Underground Laboratories, shielding of cosmic rays
- Gran Sasso (Italy)
- Soudan mine (Minnesota, US)

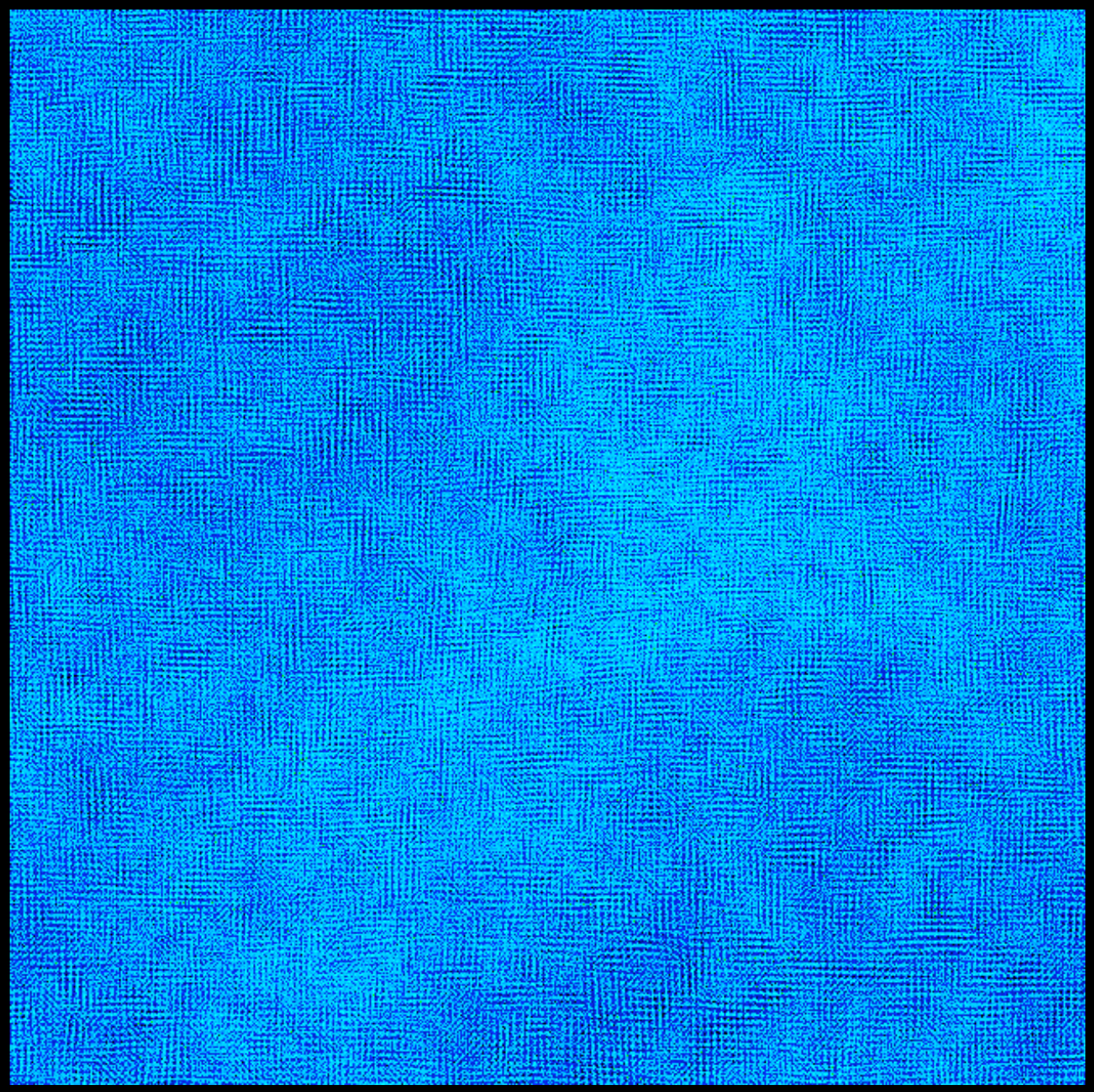
* Gravitational Lensing Experiments

* Neutrinos: lots of experiments!
On the right: MiniBooNe



Things are happening, stay tuned!

Simulating the Dark Matter



* Up to a few billion dark matter particles, interacting only gravitationally

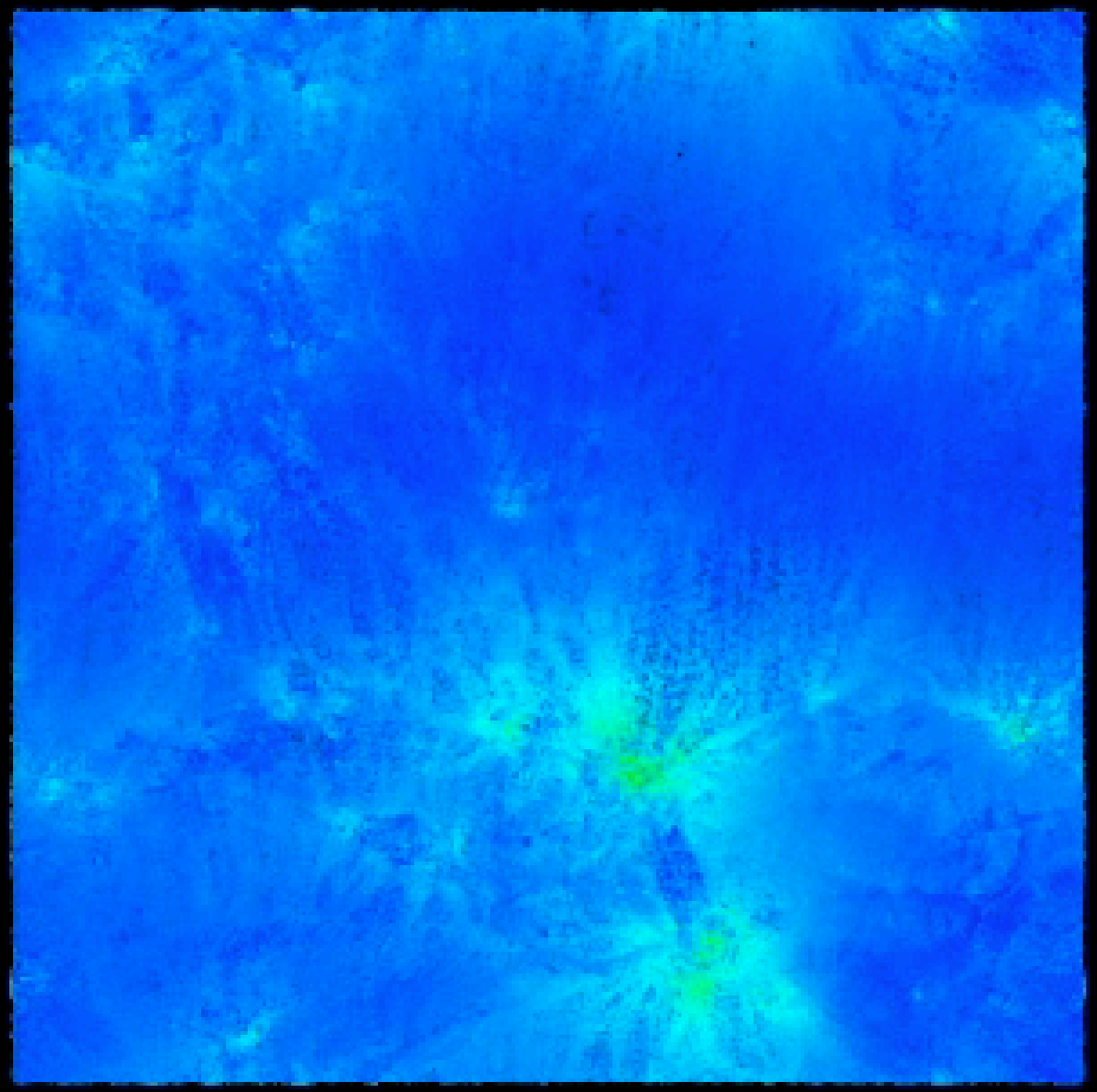
* dark energy is taken into account as cosmological constant

* start at z=50, small perturbations are imprinted

* evolve with time, gravitational forces will lead to formation of structure

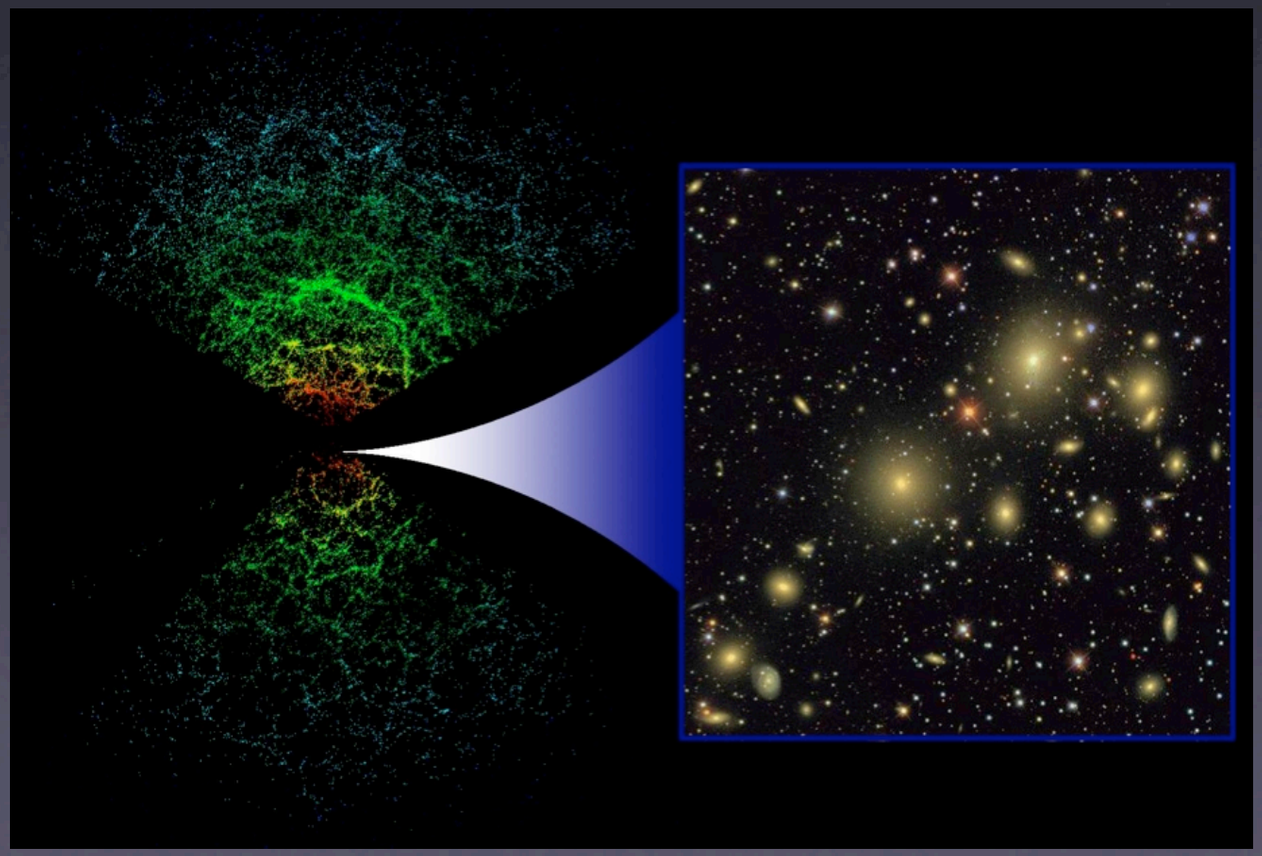
* gas is attracted, galaxies form

thanks to M.S. Warren



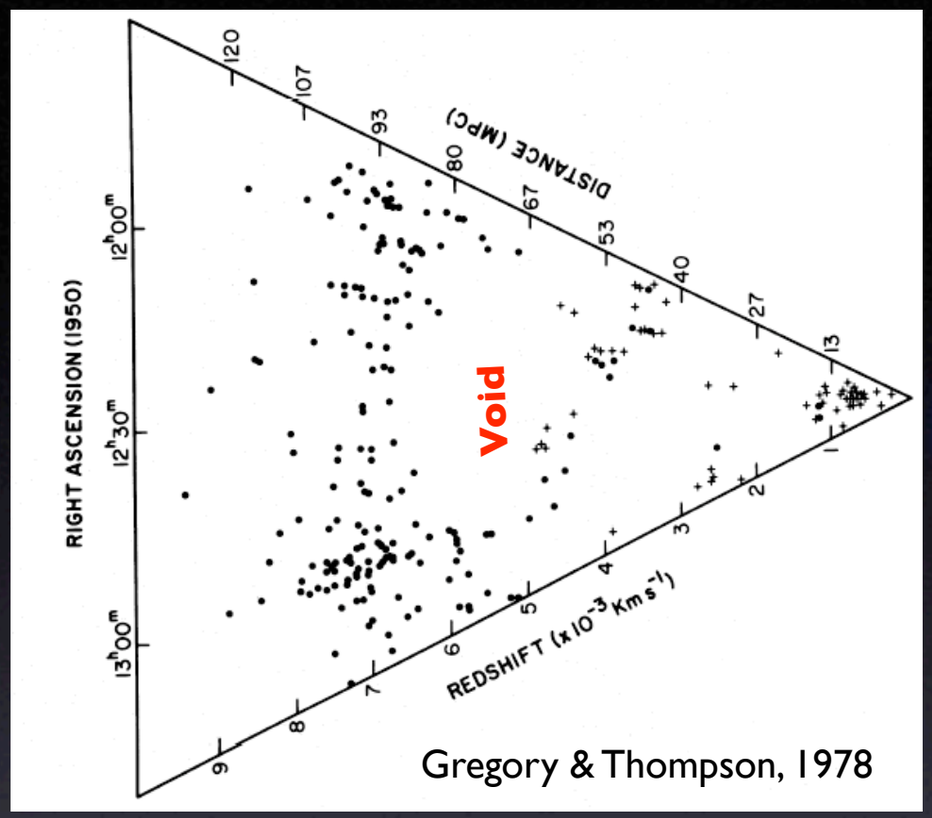
The Large Scale Structure of the Universe -- As Measured by the Sloan Digital Sky Survey

- 2.5m telescope located in NM, optical imaging and spectroscopy to create a 3-D map of the Universe
- Images from over 100 million objects, including more than 100,000 quasars and spectra from a million galaxies

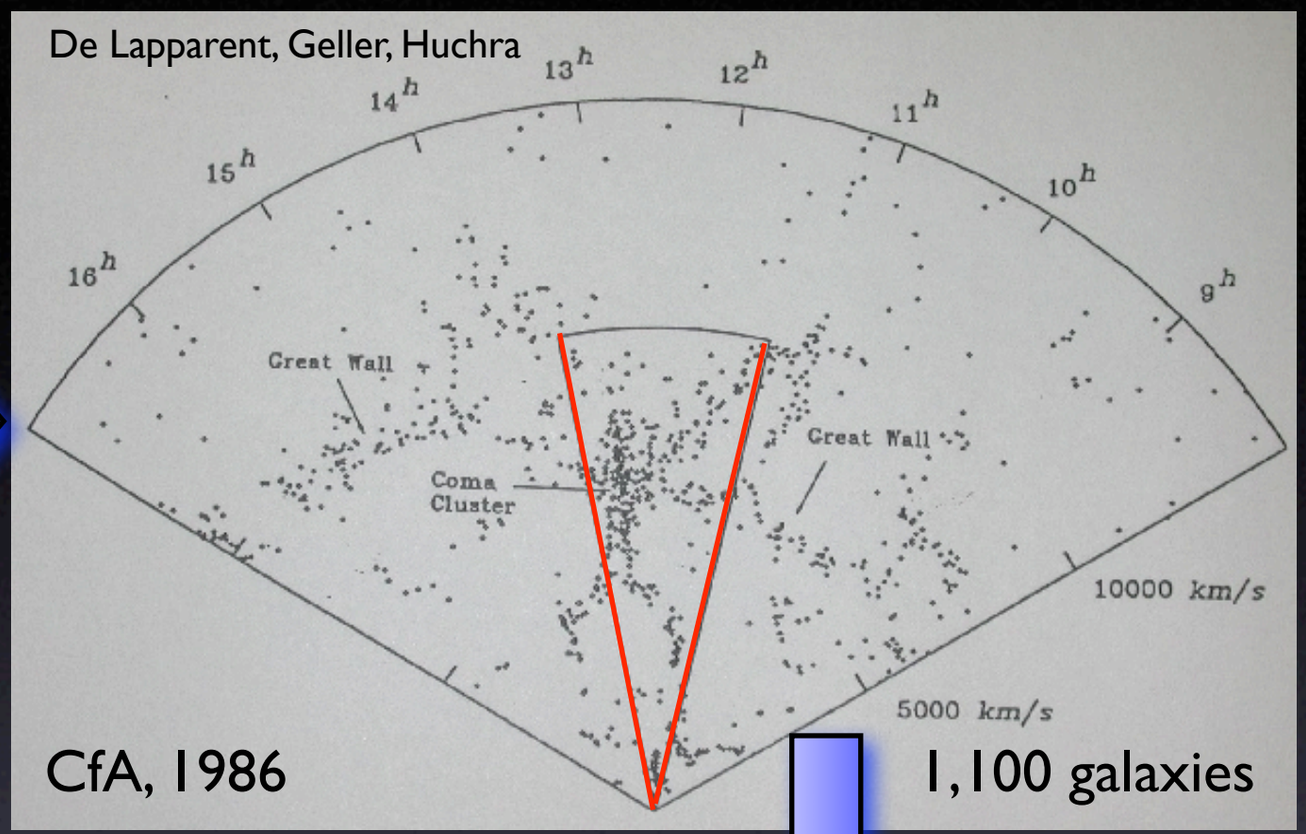


- Mapping of the large scale structure of the Universe, consisting of voids, filaments, and clusters
- Rich source for understanding the evolution and the make-up of the Universe
- LANL full member

Large Scale Structure in the Universe

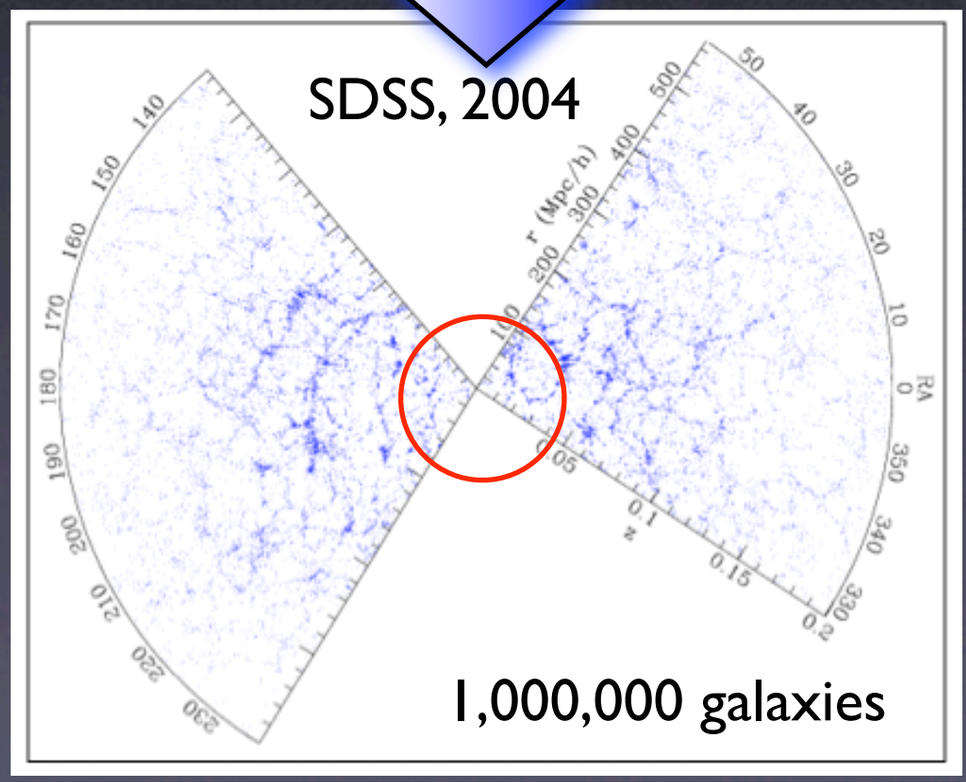


Gregory & Thompson, 1978



CfA, 1986

1,100 galaxies



1,000,000 galaxies

- 1978: Discovery of voids and superclusters, the theory of hierarchical structure formation via the gravitational instability emerges
- 2006: SDSS has measured more than 1,000,000 galaxies, important discoveries such as baryon oscillations by Eisenstein et al. cementing our picture of structure formation

GALAXY ZOO .org

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Welcome to GalaxyZoo , the project which harnesses the power of the internet - and your brain - to classify a million galaxies. By taking part, you'll not only be contributing to scientific research, but you'll view parts of the Universe that literally no-one has ever seen before and get a sense of the glorious diversity of galaxies that pepper the sky.

Why do we need you?
The simple answer is that the human brain is much better at recognising patterns than a computer can ever be. Any computer program we write to sort our galaxies into categories would do a reasonable job, but it would also inevitably throw out the unusual, the weird and the wonderful. To rescue these interesting systems which have a story to tell, we need you.

GZ is now live! Go ahead and sign up to start classifying galaxies right away.

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User Name:

Password:

Remember me next time.

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http://www.galaxyzoo.org/

How to Take Part - Tutorial

Dear heitmann

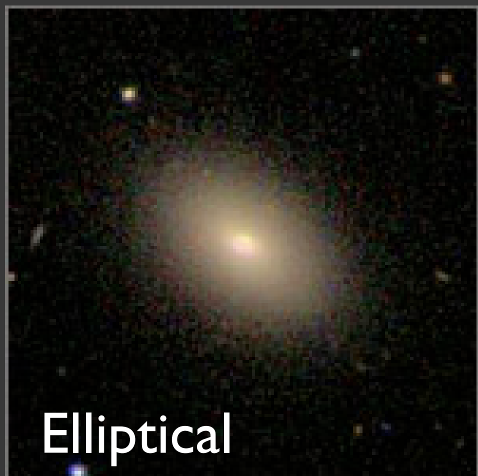
Your job is very simple! All you need to do is look out for the features that mark out sprial and elliptical galaxies. In fact, as you're a human and not a computer, most galaxies should be easy to classify since they're obviously spirals or obviously ellipticals. On this page, you will practice classifying galaxies. On the next page, you will take a short trial to test your skills. If you don't pass the trial, you can try again. Once you pass the trial, you can start contributing to Galaxy Zoo science!

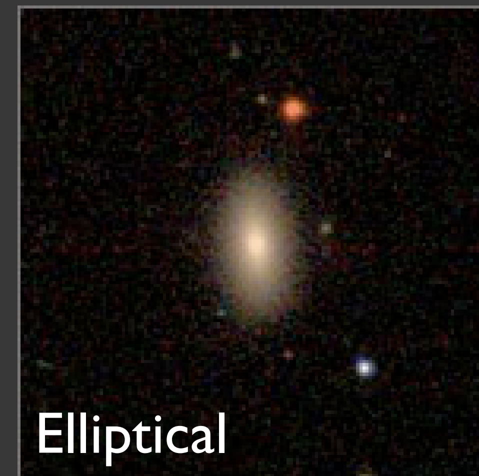
Part 1A ... Spiral or Elliptical Galaxies?

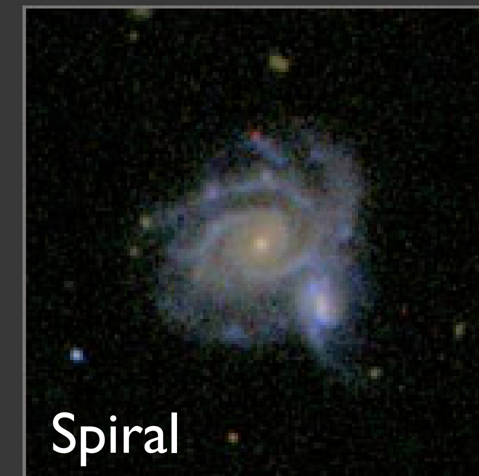
This is a face-on **Spiral Galaxy**. You can clearly see the spiral arms and a central bulge.

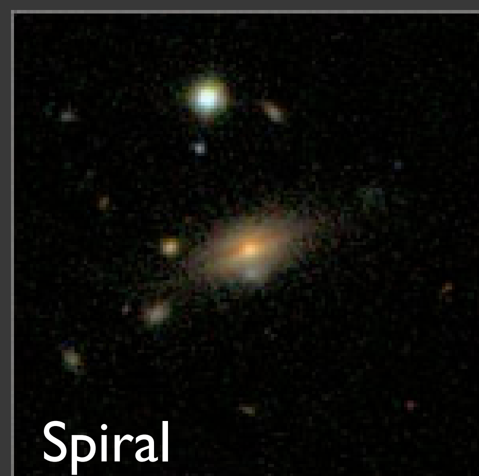
This **Elliptical Galaxy** is composed entirely of a bulge of stars. There is no disk or spiral arms.

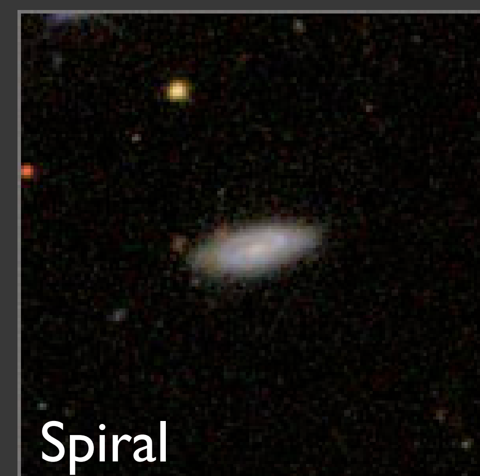
Try your hands at some!
Click the image to see if you're right.



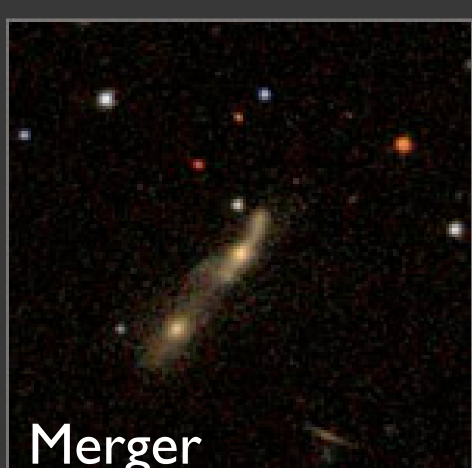


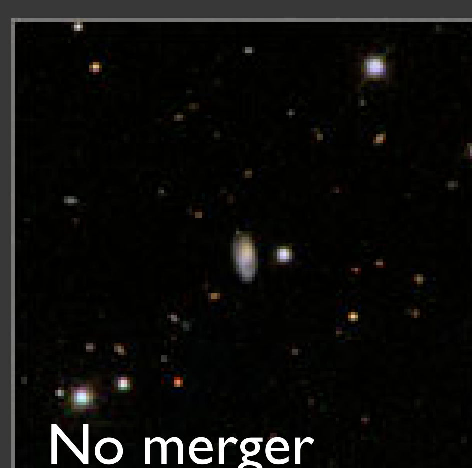


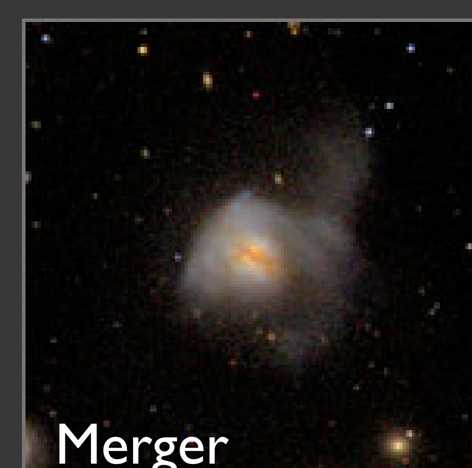


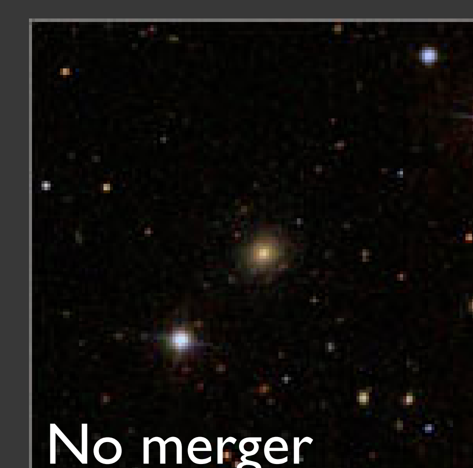


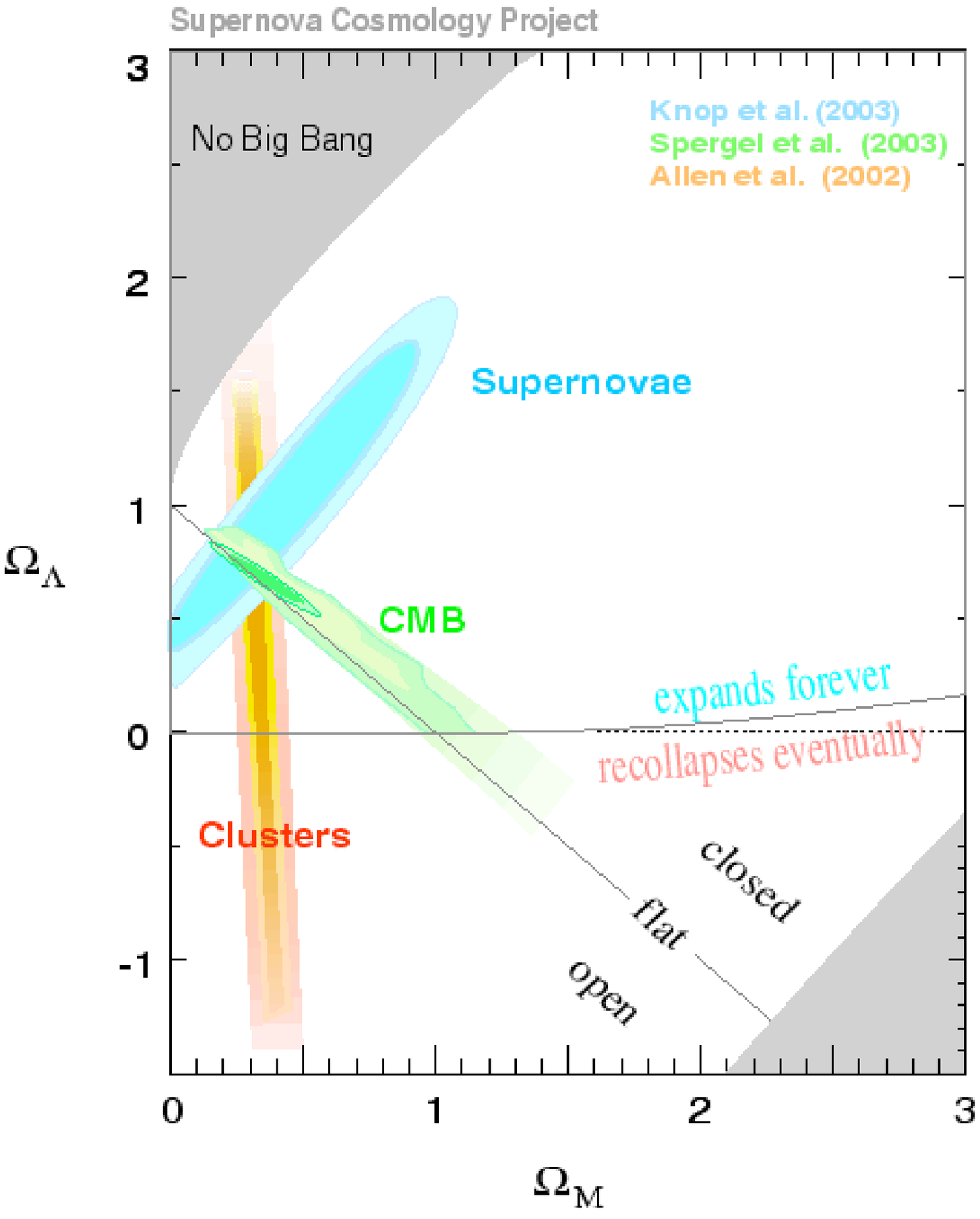
Merging or not merging?











Summary

- *Lots of different observations point to the same results: there IS dark matter and dark energy!*
- *Alternatives: e.g., MOND (Modified Newtonian Gravity) can explain perhaps one observation, but fail to deliver a consistent picture of all observations!*

The Future:

Let's find out what it is!!